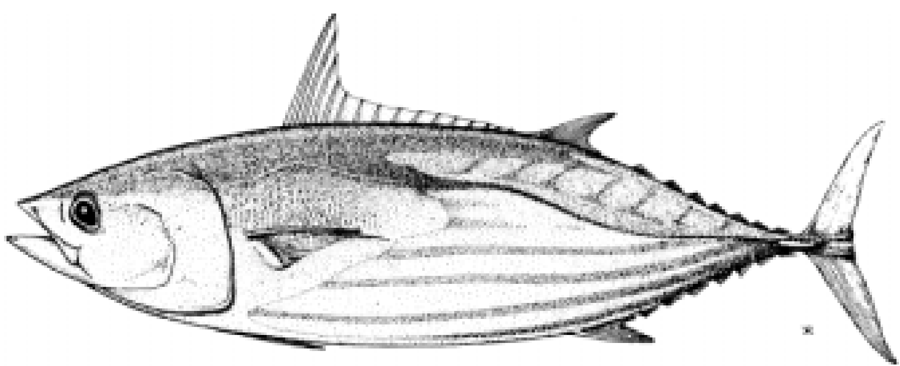
SCTB17 Working Paper

SA–5

A standardised analysis of skipjack tuna CPUE from the WCPO drifting FAD fishery within skipjack assessment area 6 (MFCL 6).



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1.0 INTRODUCTION

The current WCPO skipjack stock assessment is conducted using a spatially disaggregated age structured model implemented in MULTIFAN-CL (Langley et al. 2003). The WCPO region is divided into six sub-regions in the stock assessment (see Figure 1). Most of the annual skipjack catch is taken within the two equatorial regions, regions 5 and 6, and the stock assessment indicates these two regions account for about 90% of the total stock biomass in recent years (Langley et al. 2003).

The current stock assessment indicates skipjack biomass in regions 5 and 6 increased considerably in the late 1990s and current biomass levels are at historically high levels. The assessment model attributes the recent high biomass levels to exceptionally high recruitment in recent years. However, since the early 1990s, no direct estimates of exploitation rate are available from the equatorial area of the fishery, as previously provided from the results of large scale tagging programmes. For the recent period, the model is reliant on the available catch and effort data from the main area/method fisheries operating in these areas and from the associated length frequency data.

Since the mid 1990s, there have been considerable changes in the equatorial purse-seine fishery, particularly the development of the drifting FAD fishery. In recent years, this method has accounted for a significant proportion of the purse-seine catch in region 5 (15%) and particularly region 6 (36%). As these FAD fisheries developed, there was a considerable increase in nominal CPUE most notably within region 6 (Langley et al. 2003). The stock assessment model attempts to estimate temporal changes in catchability for each area/method fishery, although in the absence of other data from the fishery, there may be insufficient information to resolve whether changes in catch rate are attributable to changes in catchability, changes in vulnerable biomass, or a combination of both.

The purpose of this paper was to undertaken a more comprehensive analysis of the catch and effort data from the drifting FAD fishery operating within region 6. Such an analysis may enable some of the factors that may have influenced changes in catchability to be determined and, thereby, develop a more reliable index of stock abundance from the catch and effort data.

2.0 FISHERY SUMMARY

Annual trends in fishing effort and skipjack CPUE from the region 6 drifting FAD fishery were investigated. For the main fleets, these data were available aggregated by month and degree of latitude and longitude or from individual vessel logsheets.

The region 6 drifting FAD fishery developed in the mid 1990s, principally by the United States fleet and the fleet dominated the fishery until 1998 (Figure 2). In 1999, the fishery expanded considerably as Japanese and Taiwanese vessels also adopted the drifting FAD style of fishing. Total fishing effort peaked in 1999 and declined over the subsequent years, principally driven by a steady decline in fishing effort by the US fleet (Figure 2). The level of effort by the Japanese fleet also declined in recent years. A significant component of the total drifting FAD effort is now comprised of effort by vessels from “Other” flag states, principally vessels from countries party to the FSM Arrangement and New Zealand vessels (Figure 2). The Korean fleet accounts for a small proportion of the overall drifting FAD effort.

Annual trends in nominal skipjack CPUE from the US fleet increased from 1995 to a peak in 1998 and 1999, before dropping sharply in 2000 and subsequently remaining at the lower level (Figure 2).

Trends in CPUE are similar for the Japanese and Taiwanese fleets, with higher catch rates in 1998, low CPUE in 1999, and a steady increase in CPUE from 1999 to 2002 (Figure 2). However, catch rates for both fleets dropped sharply in 2003.

Catch rates from the “Other” category were relatively constant between 1998 and 2003, while catch rates from the Korean fleet varied considerably between years, partly due to the low level of fishing activity (Figure 2) – the Korean fleet undertakes predominantly free-school sets.

The aggregate fleet CPUE initially follows the trend of the US fleet, increasing from 1995 to 1998, then remains relatively constant from 1998 to 2002 before declining in 2003 (Figure 2).

Individual logsheet data were available for the US, Taiwan, and Korean fleets. These data were used to define the annual distribution of fishing effort by each sector of the fleet. The US fishery has principally operated in the Gilbert Islands (Kiribati), Tuvalu, Phoenix Islands (Kiribati), Tokelau, and adjacent international waters (Figure 3). The western extent of the fishery has varied between years, with a higher proportion of effort in the western WCPO in 1996 and 1999 (La Nina years).

In general, the US fleet has concentrated the drifting FAD fishing effort in a rectangle bounded by the equator and latitude 10°S and longitudes 170°E and 170°W (Figure 3). For the purpose of this study, this area was defined as the “core fishing area”. This core area accounted for 69% of all US drifting FAD sets from 1996 to 2003 (annual range 42% to 81%) and a similar proportion of the skipjack catch by the drifting FAD fishery.

In contrast, the Taiwanese and Korean fleets conduct most of their drifting FAD sets further west and further north than the US fleet (Figure 4 and Figure 5). For these fleets, only limited fishing activity is conducted within the US core fishing area and this is restricted to the northwestern corner of the area. Logsheet data are not available from the Japanese fleet fishing in international waters. However, an examination of complete data aggregated by degree of latitude and longitude indicates that the distribution of fishing effort is concentrated between longitudes 160°E and 180° and, as with the other fleets, there is limited overlap with the core fishing area of the US fleet.

3.0 STANDARDISED CPUE ANALYSIS

The logsheet data from the US fleet represents the most comprehensive data available from the drifting FAD fishery within region 6. The fishery has operated over a wide area in this sub-region and the spatial distribution of the fleet operation has remained relatively constant over time (Figure 3). Data from the core fishery area were used to develop standardized CPUE models of the skipjack catch from the drifting FAD fishery. The objectives of the analysis were to identify the main factors influencing the catch rate of skipjack and to investigate the potential to determine a more reliable index of relative abundance from the drifting FAD catch rate data.

3.1 Data set

The initial data set included 9,112 drifting FAD logsheet records (Figure 6). However, this was restricted to a subset from purse-seine trips where sets associated with drifting FADs was the principal fishing method for the trip (at least 60% of sets from a trip). This limited the data set to 6,599 logsheet records.

The data set included records from 1996 to 2003 (Figure 7). Fishing effort was relatively high in 1996, but declined sharply in 1997. There was a steady increase in the number of drifting FAD sets during 1998 and effort remained at a relatively constant level from 1999 until early 2002 (Figure 7). Limited fishing was conducted from mid 2002 to late 2003. Trends in quarterly skipjack catch tended to follow the overall trend in effort, although catches were considerably higher during 1999 (Figure 7).

Most (80%) of the drifting FAD sets yielded skipjack catches of less than 50 mt (Figure 8). Overall, 12% of drifting FAD sets recorded no catch of skipjack tuna, although the proportion of zero catches steadily increased from 1998 (6%) to 2003 (28%).

3.2 Generalised linear models (GLMs)

A generalized linear modeling approach was implemented using the stepAIC function in R. The model was developed to predict the observed catch of skipjack from individual drifting FAD sets. The dependent variable was the natural logarithm of the skipjack catch (in mt). A small nominal catch (0.1 mt) was added to each catch observation to avoid the inclusion of null catch values. The sensitivity of the model and the parameterization of the main variables to the inclusion of zero catch records were examined by also fitting the model without the zero catch records (denoted the non-zero model).

Initially, the CPUE models were developed using a limited number of potential explanatory variables derived from the logsheet records, with the inclusion of a variable defining the moon phase during the day fished. These potential explanatory variables are given in Table 1.

Logsheet data from drifting FAD sets included a core group of 30 US vessels, defined as vessels that received observer coverage of at least 10 drifting FAD sets per annum in a minimum of four years. These vessels were each assigned a specific vessel category. A further 22 vessels were less active in the fishery and were included in an aggregate vessel class.

A series of oceanographic variables were also derived for a subset of the logsheet data from 1998–2002. These variables were determined from various oceanographic data sets listed in Table 2. The relatively broad spatial and temporal scale of the oceanographic data (generally 1–2° of latitude/longitude by month) limited the resolution of the analysis. On this basis, variables describing the prevailing oceanographic conditions were derived for each month for individual 2° squares of latitude and longitude within the core fishing area. The variables included sea surface temperature, thermocline depth, temperature at 155 m depth, chlorophyll-a concentration (sea colour), sea surface height anomaly (SSHA, altimetry data), and current flow. For most variables, the average and range of values from each month * 2° lat/long strata was calculated. A full list of the oceanographic variables is given in Table 3. Individual logsheet records were then linked to the relevant strata based on fishing date and location.

The oceanographic data set was for the period 1998 to 2002 only. No chlorophyll-a concentration data are available prior to 1998 and current flow data from 2003 were not available for inclusion in the analysis (Table 2).

Potential explanatory variables were included in the models using a stepwise procedure (forward/backward) and the improvement of each model was assessed at each iteration using Akaike's Information Criterion (AIC). Most of the continuous variables were included in the model as second order polynomial functions, although an initial examination of some of the data revealed the relationship between the dependent variable and latitude and longitude was adequately described by a simple linear function.

The various CPUE models were used to derive quarterly indices of standardized CPUE for skipjack. In addition, the paramaterization of some of the main explanatory variables was examined.

3.2 Results

Four separate CPUE analyses were conducted; including and excluding zero skipjack catch records from the data sets, and including and not including the oceanographic variables. Each of the models explained about 13% on the total variance in observed catch, with the non zero models being slightly more informative than the models including the zero catches (Table 4 and Table 5).

An examination of the residuals of the individual models revealed a poor fit for the null catches of skipjack. On this basis, the non zero models were considered more robust, although they do not account for any temporal change in the proportion of null catches.

All models included the year/quarter, yellowfin catch, vessel-id, month, hour, and moon phase (Table 4 and Table 5). The initial model also included both latitude and longitude although these variables were not significant in the models including oceanographic data. Instead, a number of different oceanographic variables were included, principally defining the sea temperature (either at the surface or at 155 m), the chlorophyll-a concentration, current flow, and SSHA. However, while a number of the oceanographic variables were statistically significant, their individual explanatory power was low and in total only explained less than 1% of the observed variation in catch (Table 5).

For the entire data set, the quarterly CPUE indices reveal an increase in catch rate from 1996 to a peak in early 1998 (Figure 9). There was a subsequent decline in the CPUE indices to a very low level in late 2002 and early 2003. The indices increased sharply in the second quarter of 2003. The standardized indices, including or excluding zero catches, revealed a very similar trend to the trend in nominal CPUE, although the standardized indices, in particular the series including zero catches were more variable, with higher relative CPUE during 1998 than for the nominal series (Figure 9).

The models predict skipjack catches to be highest in the morning (around dawn) and this corresponds to the period of highest fishing activity.

The shorter time-series of quarterly CPUE indices incorporating the oceanographic data were also comparable to the nominal CPUE (Figure 10). The series revealed a 75% decline in CPUE from 1998 to mid 2002. The extent of the CPUE decline was consistent with decline in the CPUE indices from the entire data set.

The parameterization of the main variables was generally comparable between the four models. Monthly catch rates peaked in March, were low during the austral winter (May–September), and increased in spring to a peak in November (Figure 11). Catch rates were low in December and January.

Catches of skipjack are predicted to increase steadily with increased catches of yellowfin up to a threshold level (Figure 11). For catches of yellowfin exceeding 30 mt, the associated catch of skipjack is predicted to reduce slightly.

Catches of skipjack are predicted to be highest around the time of the full moon (+/- 2 days) and lower during the new moon (Figure 11).

For the main oceanographic variables, catches of skipjack are predicted to be highest when the sea temperature at 155 m is in the lower range of observations (Figure 11). This variable is presumably directly correlated with the depth of the thermocline and the vertical distribution of the species will be limited by the temperature at depth.

The current_east variable quantifies the magnitude of the net current flow in the area immediately east of the fishing activity. Higher catch rates were associated with stronger positive flows (eastward flow) in the vicinity, while lower catch rates corresponded to negative flows (westward flow) (Figure 11). This indicates catch rates are greatest when skipjack are being carried by eastward currents. Catch rates are also highest when there is limited northward or southward current flow (Figure 11).

The prevailing oceanographic conditions during the period of high (mid 1999) and low (mid 2002) catch rates are illustrated in Figures 12 and 13, respectively. The earlier period is characterized by generally eastern or neutral currents in the vicinity of the core fishery area and strong western currents around the equator. The thermocline is also relatively shallow in the main fishing area (100–120m depth). By contrast, during August 2002, currents were generally south- and westward and the thermocline was considerably deeper (Figure 13).

The other two oceanographic variables included in the skipjack CPUE model were the range in values for sea colour (*colour_range*) and SSHA (*SSHA_range*). Catch rates were predicted to be highest for intermediate values of both variables (Figure 11).

4.0 DISCUSSION

The analysis reveals that there are considerable differences in the trends in catch rates of skipjack from drifting FADs between the United States fleet and the other main fleets operating within the assessment region 6 (see Figure 2). These differences may, at least partly, be attributed to spatial differences in the operation of the fishery. The US fleet operates over a wider area of region 6 and extends fishing further eastward than the other fleets. On this basis, the annual catchability of skipjack and possibly the length composition of the catch are likely to differ from the other fleets operating in the fishery.

Currently, the catch, effort, and length data from all drifting FAD sets are aggregated as a single fishery in region 6. Future assessments of skipjack using MULTIFAN-CL should consider treating the US component of the data as a separate fishery in the analysis, particularly given the variable proportion of the total effort attributable to the US fleet over the recent history of the fishery.

The standardized CPUE analysis incorporated a large number of potential explanatory variables to account for the variation in the observed skipjack catch. However, the resulting models had relatively low explanatory power and the quarterly indices were very similar to the nominal CPUE series from the fishery. Nevertheless, the models revealed some consistent variables that account for at least some of the observed variation, principally month, associated catch of yellowfin, moon phase, and there are clear differences of the performance of individual vessels.

The addition of a number of oceanographic variables to the CPUE models was not particularly informative. It may be that the relatively broad spatial and temporal resolution of these data was inadequate to index the prevailing oceanographic conditions at the scale of the purse-seine fishing operation. Similarly, other parameterizations of the oceanographic data may prove to be more informative than those assessed in the current analysis.

The CPUE indices reveal considerable variation in the quarterly catch rate of skipjack from 1996 to 2003. Catch rates increased by at least 100% from 1996 to 1998 and then declined to a very low level in 2002/03. This trend is likely to be driven by an underlying trend in abundance of skipjack in the area fished. However, there are contrary trends in CPUE from other areas within region 6 that indicate that changes in US CPUE are related to changes in spatial/temporal availability i.e. catch rates for both the Japanese and Taiwanese fleets increased, while catch rates declined for the US fleet. On this basis, it would appear the US drifting FAD CPUE does not provide a reliable index of the abundance of skipjack biomass within region 6.

There are also likely to be factors influencing the vertical distribution of skipjack that influence the extent of association with drifting FADs and purse-seine catchability. The results from recent archival tagging of skipjack tuna in the Eastern Pacific Ocean may provide some insights into the factors influencing catchability (K. Schaefer, pers. comm.).

In comparison to the free-school purse-seine fishery, CPUE data from the drifting FAD fishery intuitively provides a more feasible method of monitoring skipjack abundance. Fishing effort associated with drifting FADs is more broadly distributed compared to concentrated fishing effort on highly aggregated schools of fish. Further, a drifting FAD potentially samples fish from over a wide area and, thereby, provides an estimate of the density of fish throughout the area covered by the FAD. However, as indicated by the US fishery, it is evident that the proportion of the vulnerable population sampled by the FAD fishery may vary considerably between years and, as yet, these changes in catchability have not been adequately explained by the available oceanographic data.

Further, the rapid technological advance in the drifting FAD fishery, particularly through the application of satellite and sonar technology (Itano 2003), has meant that effective fishing power of a vessel in the fishery is likely to have increased considerably since the mid 1990s. Unfortunately, very limited quantitative data are available to describe the adoption of new technology and the increase in efficiency has not been quantified. A detailed analysis of the drifting FAD fishery is also frustrated by the lack of data on the number of active FADs used by a vessel, changes in the design of FADs, the location of FAD deployments, and the duration between fishing activities on individual FADs.

References

Itano, D.G. (2003). Documentation and classification of fishing gear and technology on board tuna purse seine vessels. Working Paper FTWG-3. Sixteenth meeting of the Standing Committee on Tuna and Billfish, 9–16 July 2003, Mooloolaba, Australia. Secretariat of the Pacific Community, Noumea, New Caledonia. 31 pp.

Langley, A.; Ogura, M.; Hampton, J. (2003). Stock assessment of skipjack tuna in the western and central Pacific Ocean. Working Paper SKJ-1. Sixteenth meeting of the Standing Committee on Tuna and Billfish, 9–16 July 2003, Mooloolaba, Australia. Secretariat of the Pacific Community, Noumea, New Caledonia. 46 pp.

Table 1: Potential explanatory variables included in the skipjack FAD CPUE model.

Variable	Data type
Year/quarter	Categoric
Month	Categoric
Hour	Categoric
Yellowfin catch	Continuous, polynomial
Vessel-id	Categoric
Latitude	Continuous, linear
Longitude	Continuous, linear
Moonphase	Continuous, polynomial

Table 2: Sources of oceanographic data used to derive oceanographic variables.

Variable	Resolution		Period	Source
	Temporal	**Spatial**		
Sea surface temperature	Monthly	1.5°long, 1°lat	All years	NCEP http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.Pacific/
Temperature at 155 m	Monthly	1.5°long, 1°lat	All years	NCEP http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.Pacific/
Thermocline depth	Monthly	1.5°long, 1°lat	All years	NCEP http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP/.EMC/.CMB/.Pacific/
Chlorophyll-a concentration	Monthly	Approx. 1°long, 1°lat	1998 onwards	SeaWiFs http://seawifs.gsfc.nasa.gov/SEAWIFS.html
Current flow	Monthly	1.5°long, 1°lat	All years	NOAA NCEP EMC CMB Pacific
Sea surface height anomaly	10 days approx.	Satellite track	1992 onwards	TOPEX, SSALTO/DUACS http://ibis.grdl.noaa.gov/SAT/hist/tp_products/topex.html

Table 3: Additional potential explanatory variables included in the skipjack FAD oceanographic CPUE model.

Variable	Description
SST_average	Average monthly sea surface temperature in 2° lat/longitude.
SST_range	Range of average monthly sea surface temperature in 2° lat/longitude.
Colour_average	Average monthly chlorophyll-a concentration in 2° lat/longitude.
Colour_range	Range of monthly chlorophyll-a concentration in 2° lat/longitude.
Thermocline_depth_avg	Average monthly depth of 27°C isotherm in 2° lat/longitude.
Thermocline_depth_range	Range of monthly depth of 27°C isotherm in 2° lat/longitude.
Temp155	Average sea temperature at 155 m in 2° lat/longitude.
Current	Total monthly vectoral current flow in 2° lat/longitude.
Current_north (south)	Total monthly vectoral current flow in 5° latitude to the north (south) of 2° lat/longitude cell. Positive values northward flow; negative values southward.
Current_east (west)	Total monthly vectoral current flow in 5° longitude to the east (west) of 2° lat/longitude cell. Positive values eastward flow; negative values westward.
SSHA_average	Average monthly SSHA in 2° lat/longitude.
SSHA_range	Range in monthly SSHA in 2° lat/longitude.

Table 4: Percentage of variance (R^2) in skipjack catch explained by the standardized CPUE models including all records and only the non zero records with the addition of each successive explanatory variable.

Iteration	Variable	All	Non zero
1	Year/quarter	4.8	6.4
2	YFT catch	9.1	11.2
3	Vessel-id	10.6	12.9
4	Moonphase	11.7	13.5
5	Month	12.2	14.4
6	Hour	12.7	14.7
7	Latitude	12.8	14.7
8	Longitude	12.9	14.8

Table 5: Percentage of variance (R^2) in skipjack catch explained by the standardized oceanographic CPUE models including all records and only the non zero records with the addition of each successive explanatory variable.

Iteration	All		Non zero	
	Variable	**Percentage**	**Variable**	**Percentage**
1	Year/quarter	5.4	Year/quarter	6.4
2	YFT catch	9.8	YFT catch	11.2
3	Moonphase	10.5	Month	12.3
4	Month	11.3	Vessel-id	13.0
5	Vessel-id	11.9	Moonphase	13.5
6	Current_west	12.2	Current_east	13.9
7	Temp155	12.4	Colour_range	14.1
8	SSHA_range	12.5	Current_north	14.2
9	Colour_average	12.7	Temp155	14.3
10	SST_average	12.8	Hour	14.4
11	Hour	12.8	SSHA_range	14.5
12	SST_range	12.9		
13	SSHA_average	13.0		
14	Current	13.1		

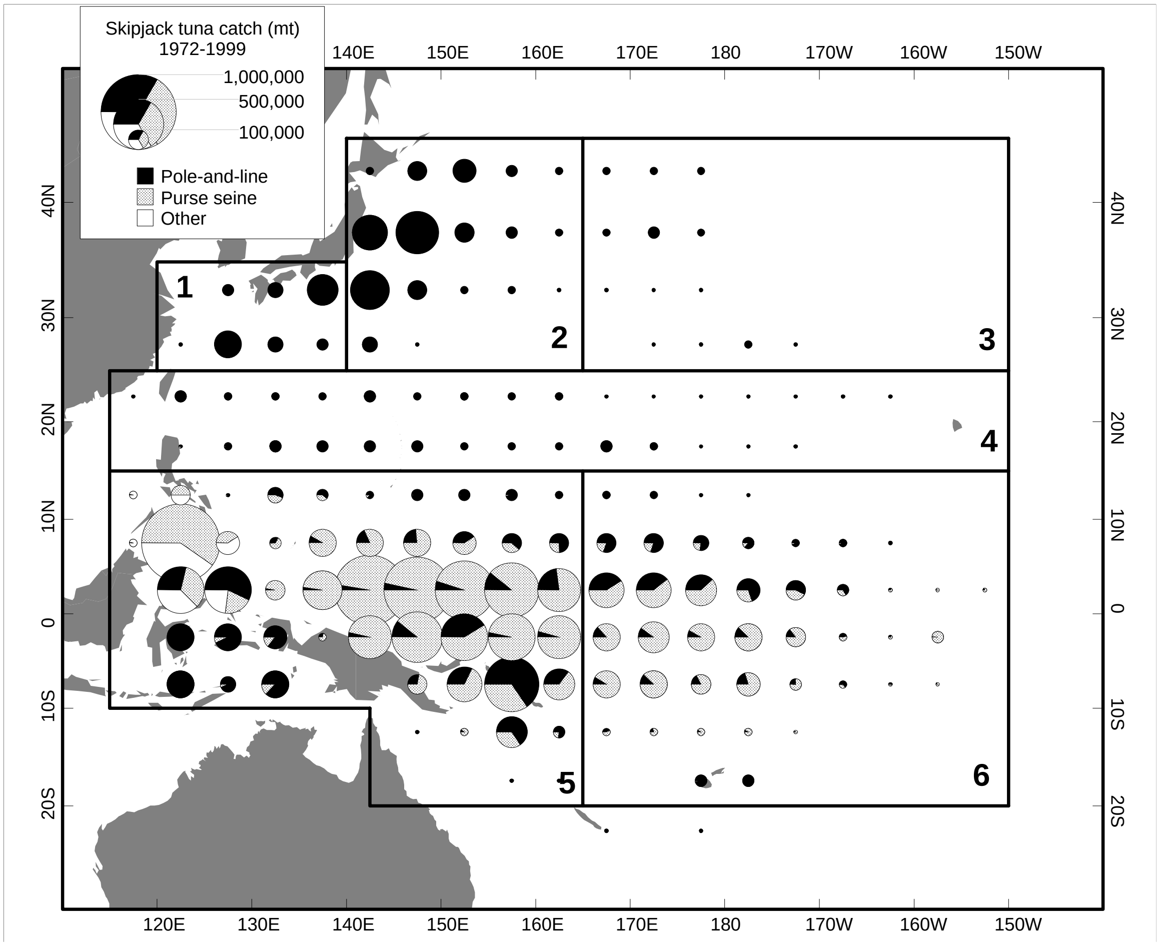

Figure 1. Distribution of total skipjack catches 1972–1999 in relation to the six-region spatial stratification used in the MULTIFAN-CL analysis (from Langley et al. 2003).

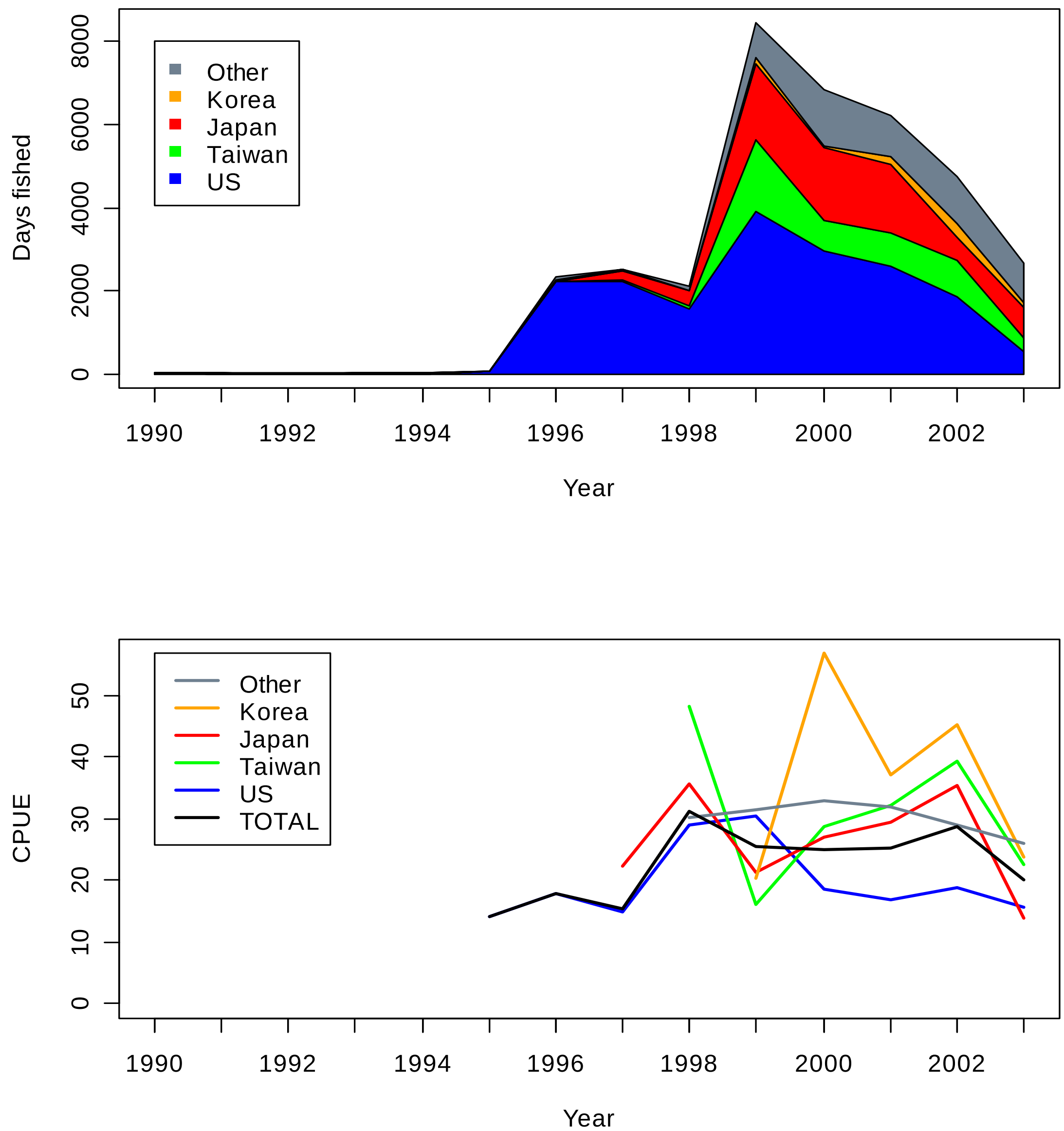

Figure 2: Trends in total effort (days fished; top) and nominal skipjack CPUE (mt per day fished) from the drifting FAD fishery within region 6 of the skipjack stock assessment by year for the main fishing fleets.

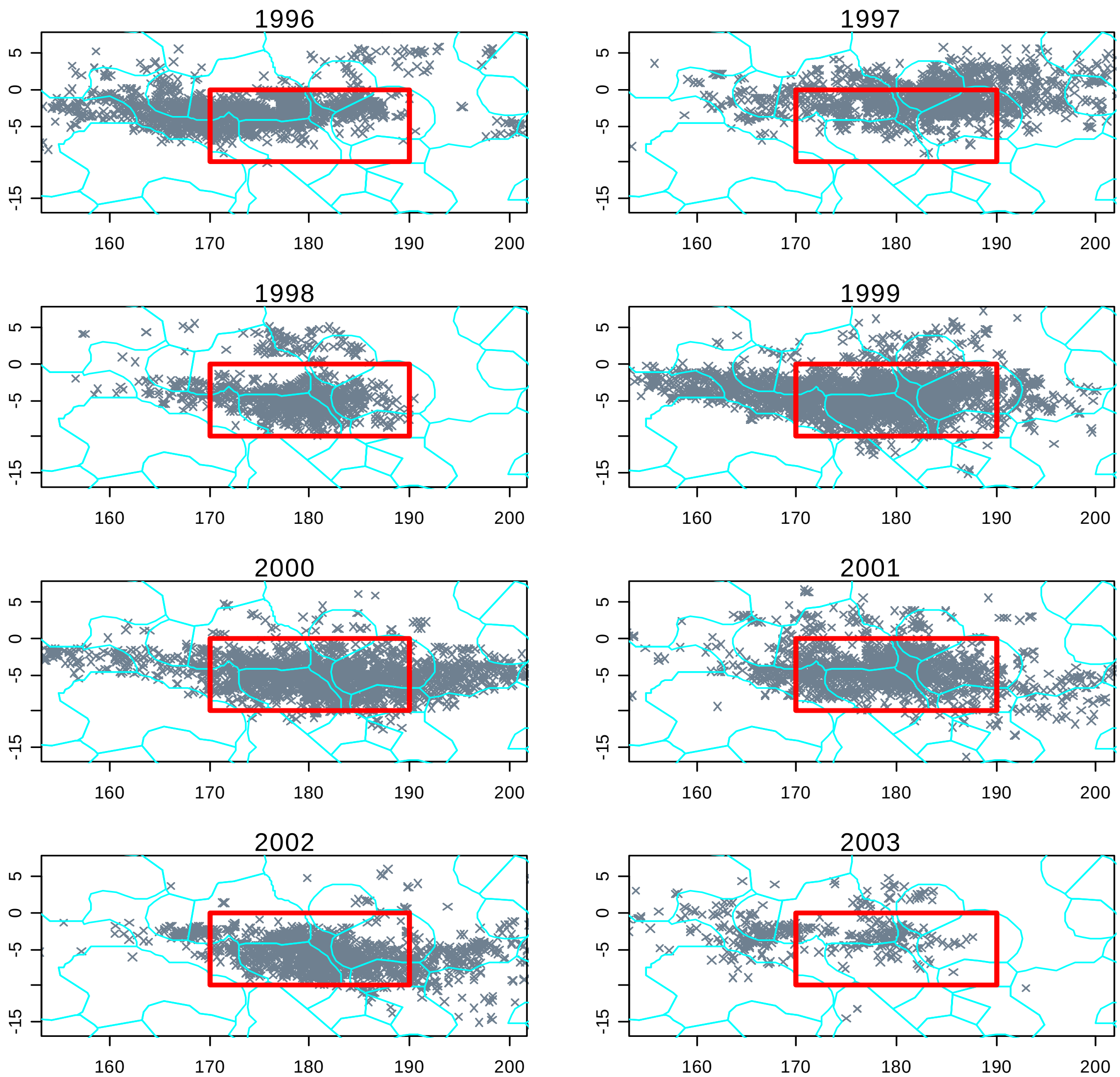

Figure 3: Annual distribution of drifting FAD sets conducted by the US fleet. The red box represents the core area defined for the US fleet. The light blue lines represent the EEZ boundaries.

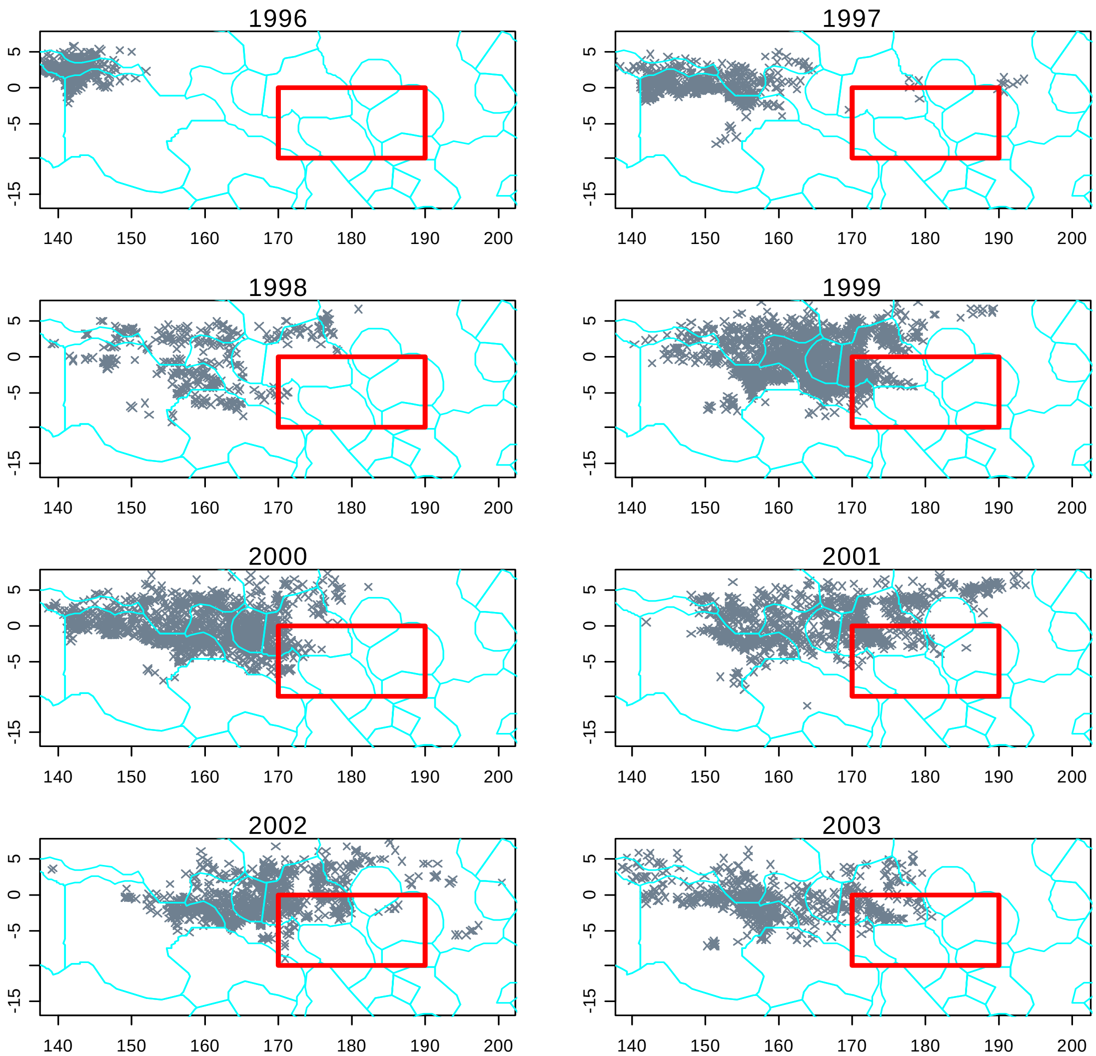

Figure 4: Annual distribution of drifting FAD sets conducted by the Taiwanese fleet. The red box represents the core area defined for the US fleet. The light blue lines represent the EEZ boundaries.

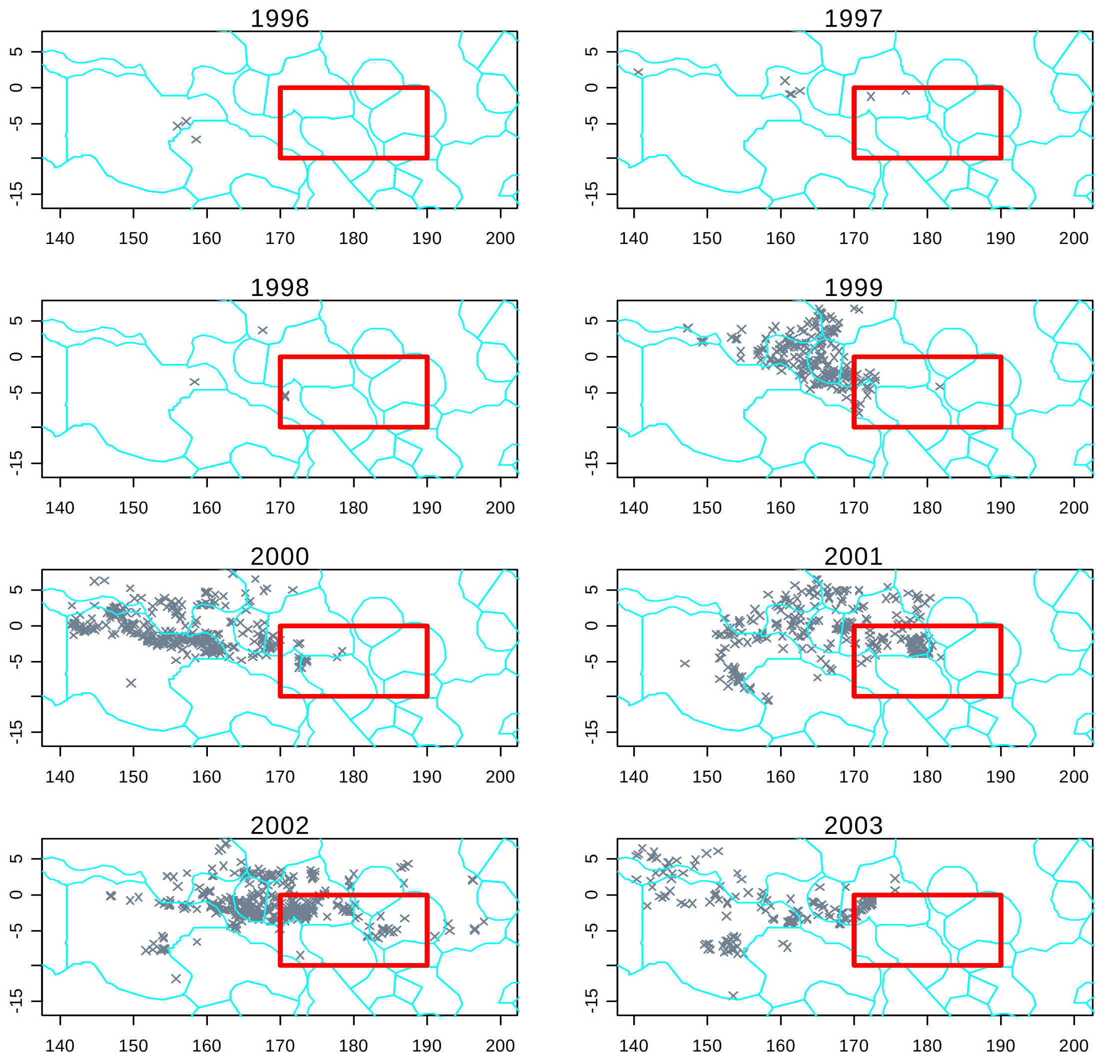

Figure 5: Annual distribution of drifting FAD sets conducted by the Korean fleet. The red box represents the core area defined for the US fleet. The light blue lines represent the EEZ boundaries.

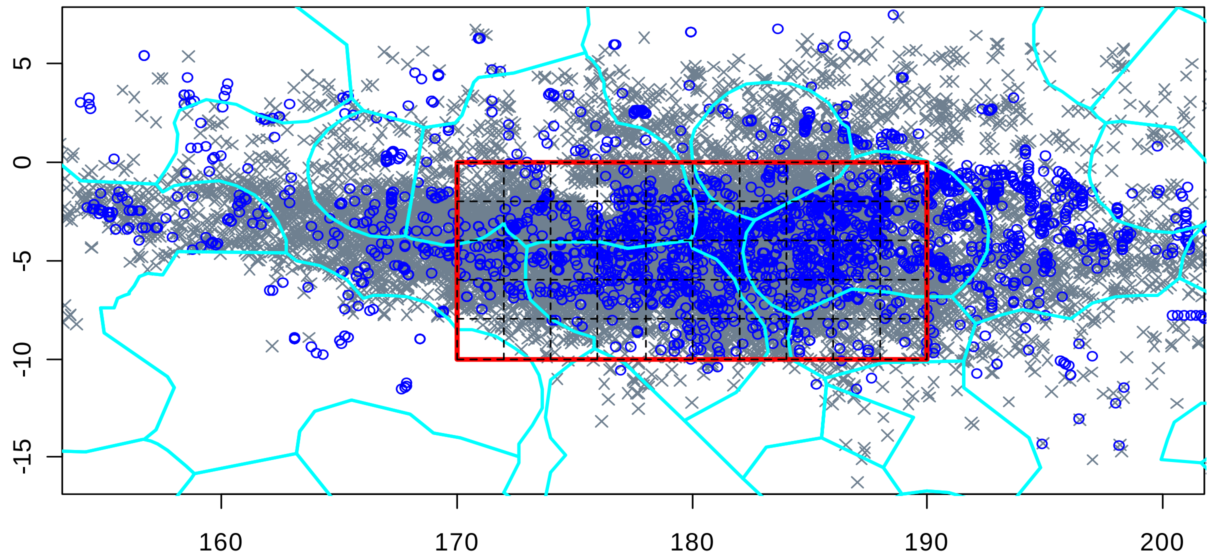

Figure 6: Location of all US drifting FAD purse-seine set (gray crosses) locations from logsheet records and the location of observed drifting FAD deployments (USMLT observer data) for all years combined. The red box represents the core fishery area. This area was subdivided into 50 two degree squares used to determine the oceanographic parameters.

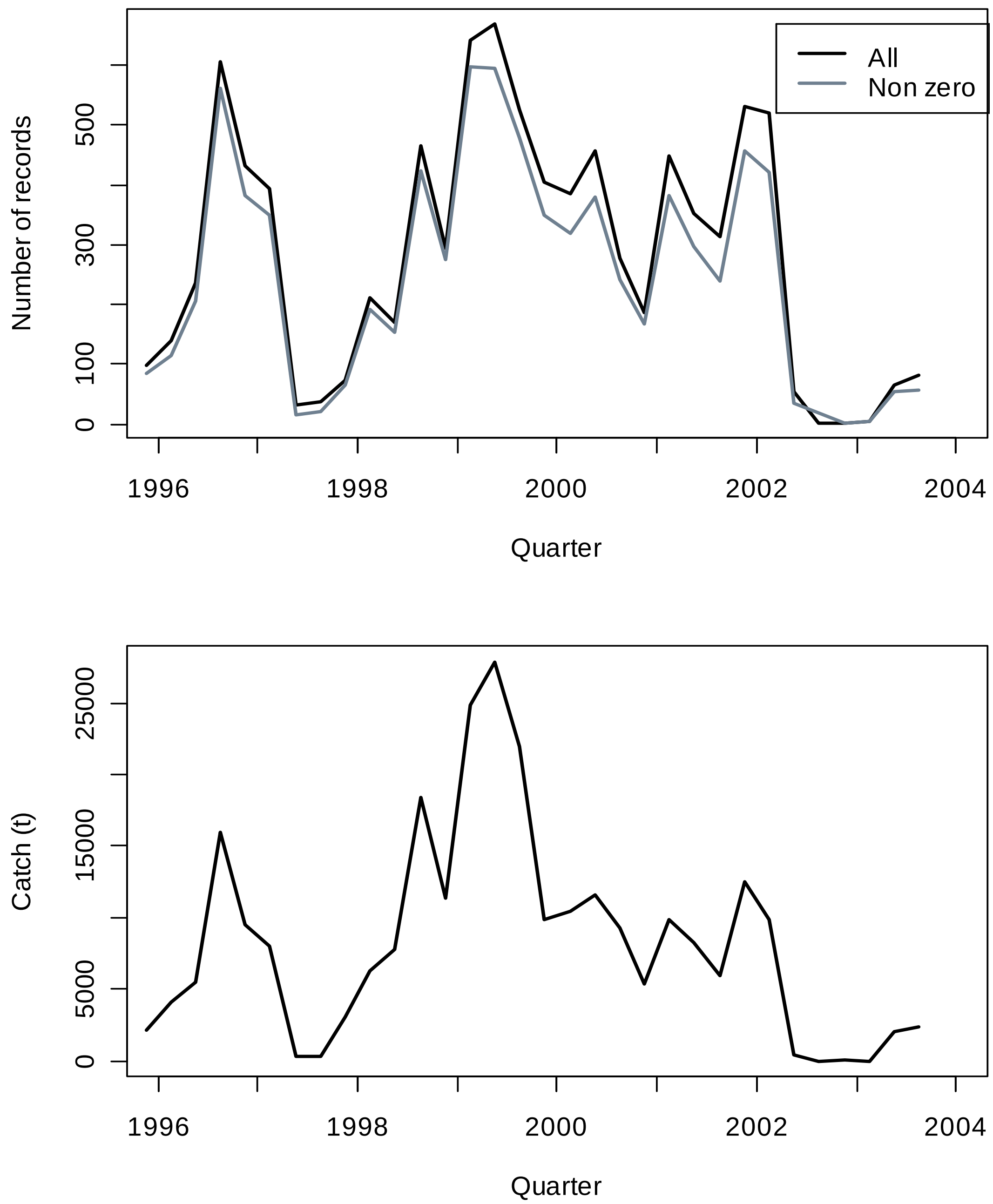

Figure 7: Total number of records and number of records with skipjack catch (top) and total skipjack catch (mt) (bottom) by quarter included in the US drifting FAD CPUE data set.

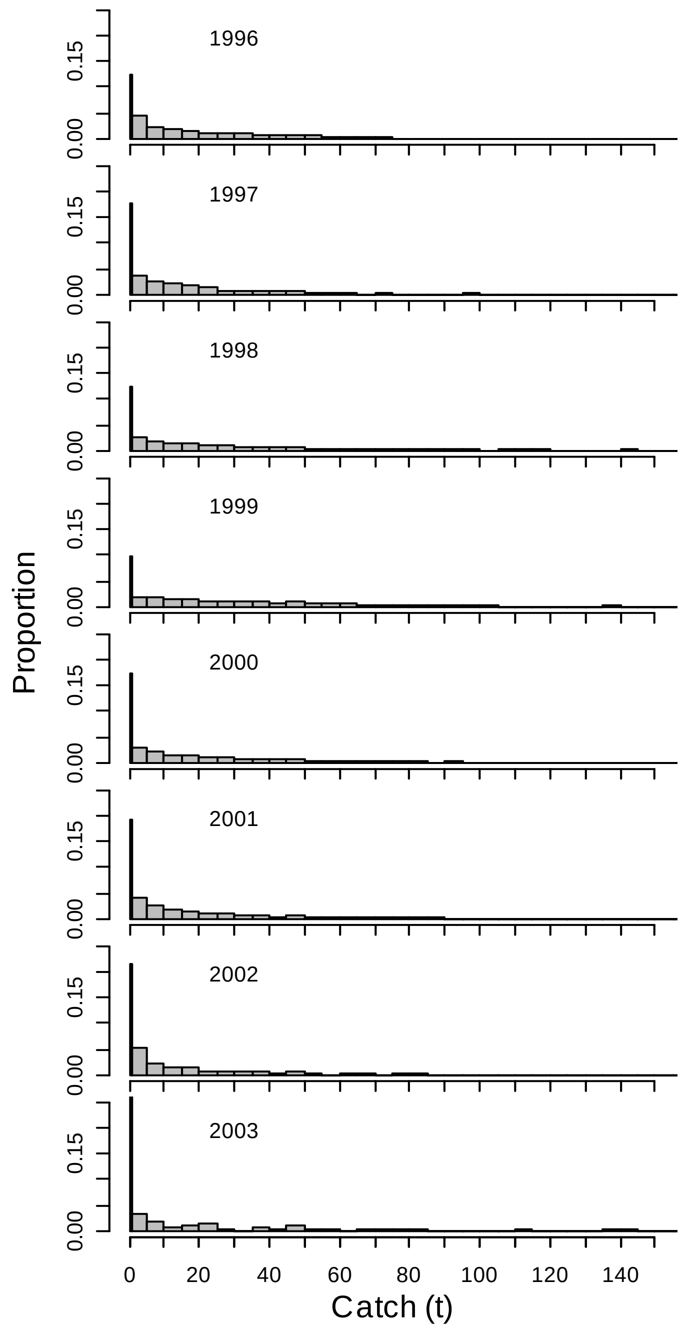

Figure 8: Skipjack catch (mt) distribution by year for the US drifting FAD fishery operating in the core fishery area.

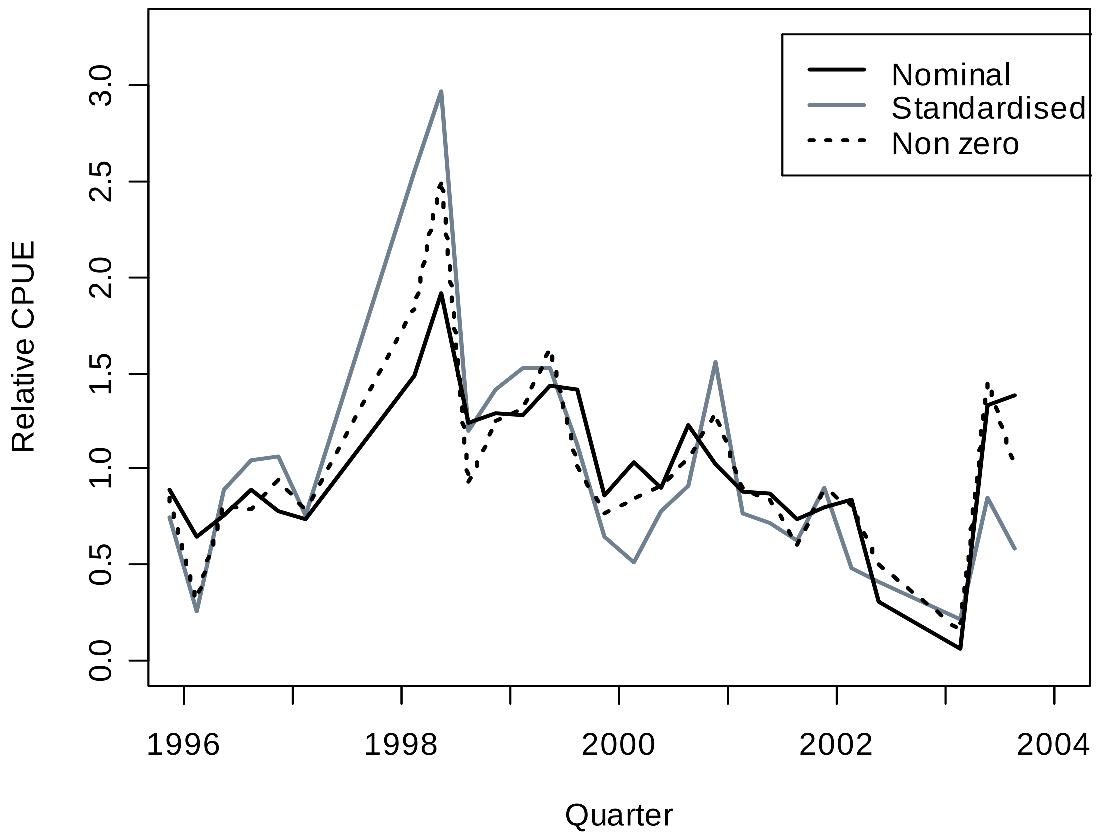

Figure 9: Quarterly skipjack CPUE indices from the standardized analyses (including and excluding zero catch records) without oceanographic data. The nominal CPUE (mean catch per set) is also plotted for comparison. All indices are scaled to the mean of the series.

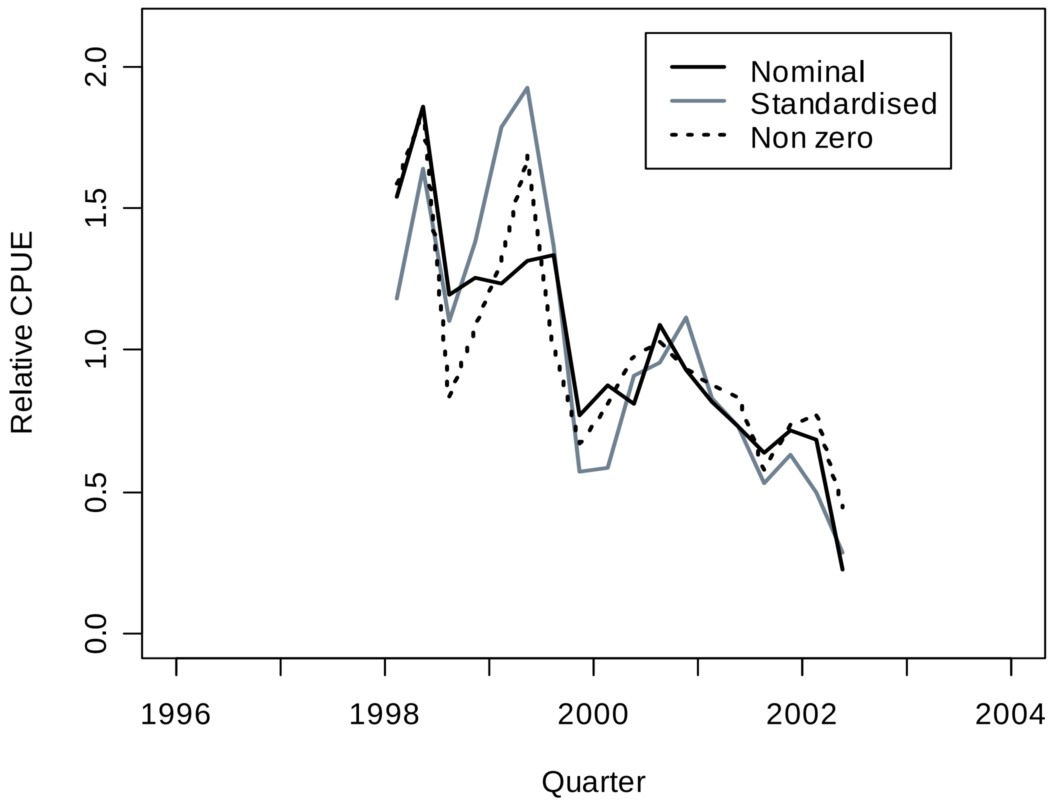

Figure 10: Quarterly skipjack CPUE indices from the standardized analyses (including and excluding zero catch records) with the inclusion of oceanographic data. The nominal CPUE (mean catch per set) is also plotted for comparison. All indices are scaled to the mean of the series.

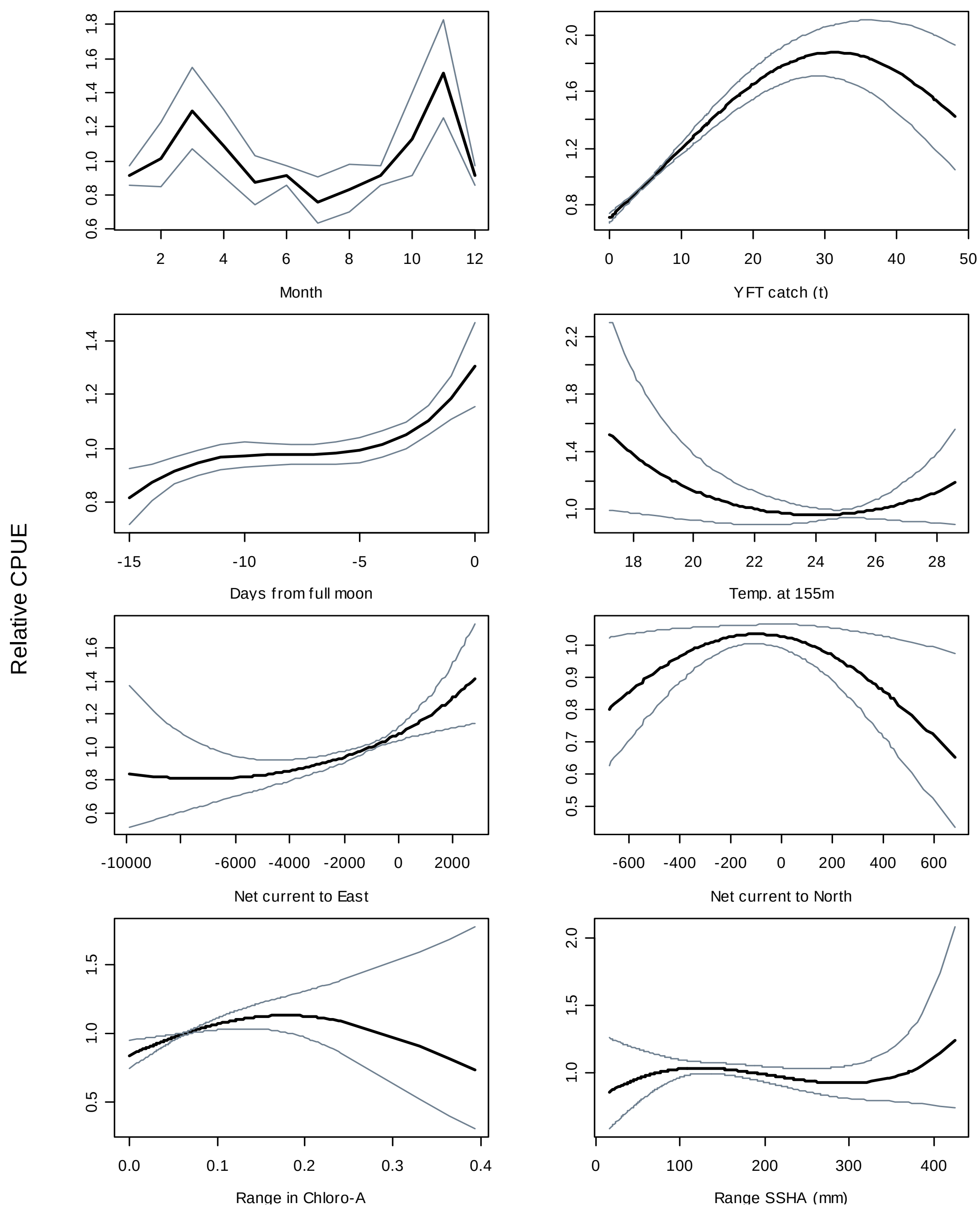

Figure 11: Parameterisation of the main effects of the non zero oceanographic CPUE model. The confidence intervals represent +/- 2 standard deviations.

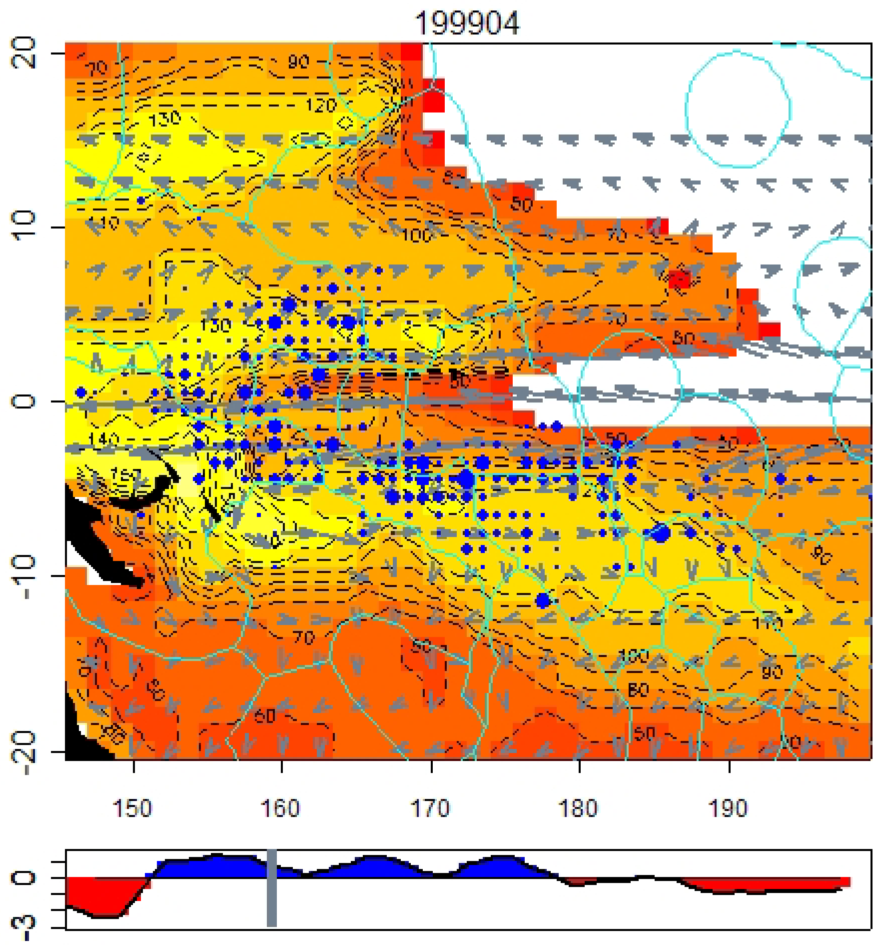

Figure 12: Monthly distribution of purse-seine skipjack catch (blue circles) from unassociated sets in the WCPO during April 1999. The area of the blue circle is proportional to the total monthly skipjack catch from a degree of latitude and longitude. The catches overlay the depth of the thermocline (27°C). The depth of the thermocline is represented by the colour from shallow (red) to deep (yellow). Contour lines represent the depth of the thermocline in metres. The arrows represent the direction and strength of the prevailing sub-surface (50 m) currents. The lower panel represents the SOI for the month (gray vertical line) relative to the longer-term trend.

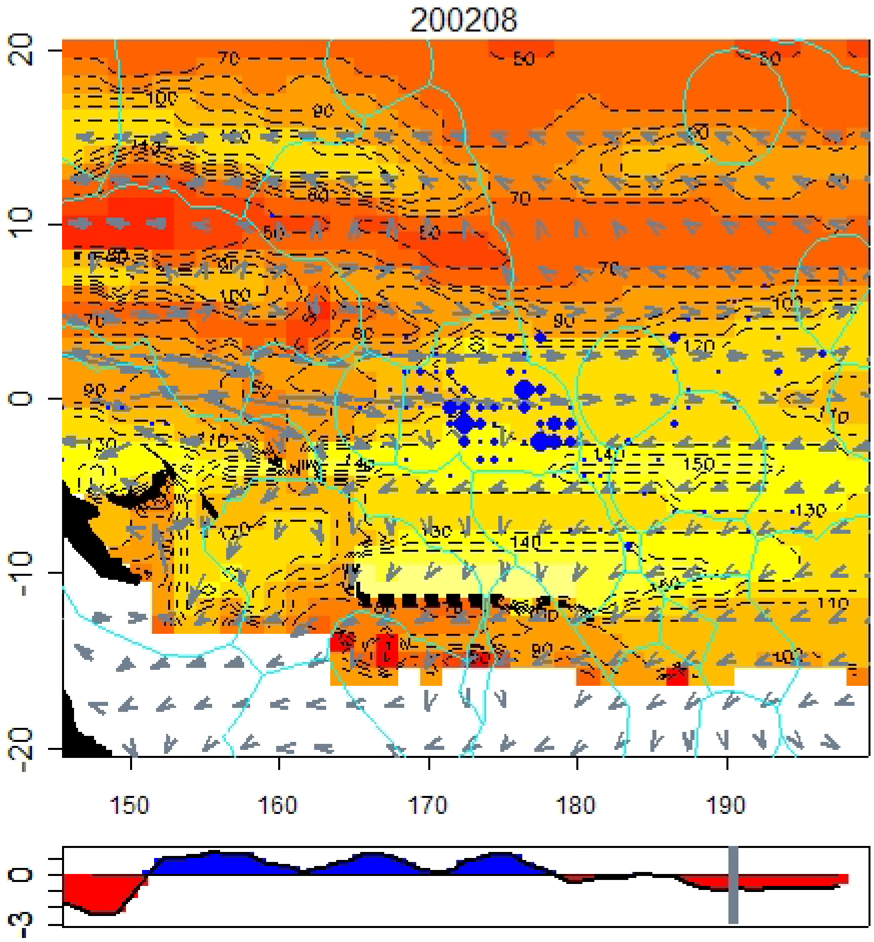

Figure 13: Monthly distribution of purse-seine skipjack catch (blue circles) from unassociated sets in the WCPO during August 2002. The area of the blue circle is proportional to the total monthly skipjack catch from a degree of latitude and longitude. The catches overlay the depth of the thermocline (27°C). The depth of the thermocline is represented by the colour from shallow (red) to deep (yellow). Contour lines represent the depth of the thermocline in metres. The arrows represent the direction and strength of the prevailing sub-surface (50 m) currents. The lower panel represents the SOI for the month (gray vertical line) relative to the longer-term trend.